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LATERAL-CONTROL CHARACTERISTICS OF NORTH AMERICAN

XP-51 AIRPLANE (A. C. No. 41-38) WITH BEVELED

TRAILING-EDGE ALLERONS IN HIGH-SPEED FLIGHT

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MEMORANDUM REPORT

for

Army Air Forces, Materiel Command

LATERAL-CONTROL CHARACTERISTICS OF NORTH AMERICAN

XP-51 AIRPLANE (A. C. No. 41-38) WITH BEVELED

TRAILING-EDGE AILERONS IN HIGH-SPEED FLIGHT

By Herbert H. Hoover and Maurice D. White

SUMMARY

The flight tests of beveled trailing-edge ailerons on the North American XP-51 airplane, as reported in reference 1, were extended to determine the aileron characteristics in high-speed dives.

Standard NACA recording instruments were used to determine airspeed, aileron position, stick force, and rate of roll.

The tests were carried to an indicated airspeed of approximately 492 miles per hour (520 miles per hour true airspeed) at an altitude of about 6000 feet. The maximum airspeed corresponds to a Mach number of approximately 0.69.

The results obtained show that the beveled trailing-edge form of aerodynamic balance, as used on the XP-51 ailerons, had no abnormal or unusual characteristics in high-speed flight. The aileron effectiveness and aileron hinge moments remained essentially proportional to aileron deflection at all speeds tested and there was no tendency for the ailerons to shake or overbalance.

A trim tab that was installed on the left aileron resulted in a pronounced left-wing heaviness with the tab in neutral. With the tab set in the full-up position, the airplane trimmed at both ends of the speed range tested and became a little right-wing heavy (3 lb force) at intermediate speeds. With this tab setting, stick forces required to obtain a given rate of roll were considerably greater for left rolls than for right rolls. With the tab in neutral and hinge and end gaps sealed with fabric, the left-wing heaviness due to the tab was largely eliminated up to at least 300 miles per hour, the highest speed tested in this condition; so that the characteristics were similar to those obtained with the previous experimental ailerons which had no tab. It appears advisable to avoid the use of a tab with the ailerons and to use a bungee for the slight amount of trimming then required.

INTRODUCTION

In the aileron-effectiveness tests of reference 1, in which the ailerons were modified by securing false ribs to the original surface and fastening a new skin to the ribs, the increase in weight resulting from the modification and its added mass balance amounted to about 70 percent of the original aileron weight. Because of lack of knowledge of the flutter characteristics of the wing with this added weight at the wing trailing edge, the investigation was confined to indicated airspeeds below 300 miles per hour.

In order to permit tests at higher speeds, a new pair of ailerons was built embodying the same airfoil section as the modified ailerons originally tested, but of construction similar to that of the original ailerons of the airplane and weighing about 30 percent more than the original 26 pounds.

The results of tests of the effectiveness and stick-force characteristics of these ailerons at high speeds are presented in this report. The effects of a gap between tab and aileron on beveled trailing-edge surfaces are also indicated.

AILERON INSTALLATION

The structural design of the ailerons used in the present tests was similar to that of the original XP-51 ailerons. The original main spar and hinge fittings were used, but the ribs and covering were fabricated of slightly heavier sheet than the original. The section contours were the same as those of the modified ailerons of reference 1.

A trim tab $26\frac{5}{16}$ inches in span and tapered in chord from about $4\frac{5}{32}$ inches to $3\frac{11}{16}$ inches was installed on the left wing (fig. 1); no tab was provided on the right aileron. The modified ailerons reported on in reference 1 had no tabs.

TESTS, RESULTS, AND DISCUSSION

Aileron Effectiveness and Stick Forces

The procedure used in the present tests was the same as that used to obtain the results given in reference 1. Standard NACA recording instruments were used to record stick force, aileron angle, and rolling velocity as the pilot abruptly applied aileron control from laterally level flight at various airspeeds, the rudder being held fixed at each trim position.

The results of tests made at various indicated airspeeds (defined by $V_1 = 45.08 \sqrt{\rho_{\text{cin. H}_2\text{O}}}$) are shown in figure 2 where the effectiveness, as defined by the parameter $\frac{pb}{2V}$, and stick forces are plotted against total aileron deflection. Although it was intended to perform a series of aileron

deflections at each of several indicated airspeeds, the airspeed varied somewhat in each series of runs so that it was necessary to correct the data to the average airspeed for each of the curves shown.

The maximum indicated airspeed obtained was 492 miles per hour at an altitude of about 6000 feet. This corresponds to a true airspeed of 520 miles per hour and a Mach number of 0.69.

As is shown by figure 2, the maximum value of $\frac{pb}{2V}$ of 0.084 obtained in full deflection rolls, and the effectiveness per unit control deflection for the rebuilt ailerons agree well with corresponding values for the first pair of modified ailerons, reproduced in figure 2 from reference 1. The slight increase in effectiveness per unit control deflection indicated for the rebuilt ailerons as compared with the first modified ailerons is probably within the experimental accuracy of the tests.

For the rebuilt ailerons, the stick forces required for a given deflection in rolls to the left are greater than for the first pair of modified ailerons, and are less in rolls to the right. This difference in characteristics as compared with the first pair of modified ailerons was shown by tests discussed in a later section of this report to be caused by the trim tab which was installed on the rebuilt ailerons, but not on the first modified ailerons.

In figure 3, values of $\frac{pb}{2V}$ and of the maximum rolling velocity obtainable with a stick force of 30 pounds, this value being considered a reasonable upper limit for stick forces, are plotted against indicated airspeed for the rebuilt ailerons. Results for the first pair of modified ailerons and for the original ailerons are also shown. The effect of the heavier forces required in rolls to the left is evidenced in the lower rolling velocities obtainable in left rolls as compared with right rolls at high speeds.

Specifically, the results show that at an indicated airspeed of 248 miles per hour, which corresponds to approximately 0.8 of the maximum level-flight speed, a value of $\frac{pb}{2V}$ of 0.07 is obtained in right rolls and 0.053 in left rolls for a 30-pound stick force. The average of these values, which would correspond to the condition where the unsymmetrical effects of the tab are eliminated, is indicated by the curve for the first pair of modified ailerons to be 0.061, which is less than the recommended value of 0.07.

Aileron Trim Tab Effectiveness

As originally constructed, a considerable gap existed between the trim tab on the left aileron and the aileron itself. Preliminary tests of the ailerons showed a right force of varying but rather large magnitude to be required for trim over the speed range with the tab set at neutral. It was also shown that the tab was inadequate for producing

lateral trim when deflected upward as required, but that it was effective in increasing the lateral unbalance when deflected downward.

Tests with the gap sealed on both upper and lower sides and with the tab set at neutral showed the condition of unbalance to be practically eliminated, so that throughout the speed range little or no force was required for trim. Accordingly, metal shrouds covering the gap on both upper and lower sides were installed and tested (fig. 1). With the shrouds installed, the forces necessary for trim with the tab undeflected were larger than with the gaps sealed; however, (fig. 4) in contrast with the open gaps, it was possible to trim out the forces at all speeds by deflecting the tab up. Some dissymmetry in tab effectiveness between up and down deflections still existed.

The tests of aileron effectiveness discussed in the preceding section of this report indicated that differences in aileron forces between right and left aileron deflections existed even with the shrouds over the gap. To establish the origin of these differences, a series of aileron rolls was made with the gaps at the front and ends of the tab sealed with tape. The forces required for left and right rolls were then found to be the same.

From the above results, it appears that the installation of the tab on the beveled trailing-edge aileron introduced

certain unsymmetrical effects which largely nullified the benefits of the trim tab. On this basis, it would appear desirable that the trim tab be eliminated and a different means be adopted for balancing the small forces (3 lb or less) as shown in figure 4 necessary for trim with the ailerons having no tabs/. A bungee, the action of which is independent of control deflection, could be used advantageously.

Structural Considerations

Since the deflection range for the ailerons was increased for the present tests, a study was made to determine from existing data the probable safe deflection limits for ailerons at high speeds on the XP-51 airplane. The relation between aileron strength and the applied air loads is shown in figure 5. The applied aerodynamic loads for various aileron deflections were calculated from basic pressure-distribution data on plain flaps. The aileron design loads and static test breaking loads were obtained from information supplied by the Materiel Center Liaison Office. The following extract is quoted from the communication:

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The two load conditions listed below were considered in the design of the ailerons and an aileron was static tested for the loading of condition a. Failure occurred at 115 percent ultimate load.

a. Neutral condition

L.A.A. - Triangular Distribution

Average loading - 183 pounds per square foot

Total load per aileron - 1215 pounds

Total torque per aileron - 5612 inch-pounds

b. Deflected condition

Trapezoidal loading in accordance with AAF

Spec. X-1303A

Average load per aileron - 83 pounds per square
foot

Total load per aileron - 550 pounds

Total torque per aileron - 2542 inch-pounds

The aileron control system was not included in the static tests of the aileron. The aileron control system was proof tested with a hinge moment of 1441 inch-pounds placed on both ailerons upward and ailerons deflected upward 3 degrees 37 minutes. For an inverted loading check, a down hinge moment of 783 inch-pounds was placed on both ailerons simultaneously and then deflected downward 1 degree 47 minutes. For the deflected condition a maximum upward hinge moment of 1441 inch-pounds was placed on one aileron and a maximum down hinge moment of 783 inch-pounds on the other. The aileron cables were rigged to an initial tension of 60 pounds. No permanent set resulted from any of the tests on the aileron control system.

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The aileron deflections and airspeeds at which these structural loads are developed were calculated from basic pressure-distribution data on plain flaps.

The results of these calculations are probably somewhat conservative for the beveled trailing-edge surfaces since the data for plain flaps used in the analysis do not take into account the reduction in load at the trailing edge corresponding to the balance obtained with the beveled trailing-edge shape. It should be pointed out that for plain flaps without concavity the deflected flaps have chordwise pressure distributions that are essentially triangular and should therefore be compared with structural design loads having a triangular distribution.

A detailed explanation for the three curves in figure 5 follows:

Condition I (design load for trapezoidal distribution). -

One of the conditions assumed in the structural design is an average design load of 83 pounds per square foot (applied load $1/1.5 \times 83$ lb per sq ft) with a trapezoidal distribution. The curve for condition I shows the airspeeds and deflections at which a load of $1/1.5 \times 83$ pounds per square foot would be obtained. Since wind-tunnel pressure-distribution data for plain flaps show that the load developed at these speeds and deflections would actually be triangular in distribution rather than trapezoidal, this condition is

not regarded as a rational basis for establishing the safe aileron-deflection range for flight. This conclusion is verified by an analysis of the force data of figure 2 which indicates the center of pressure of the aileron loads to be even farther forward than the $1/3$ -chord point that corresponds to a triangular distribution; hence, the torque or hinge moment indicated for a given load in the loading specifications is greatly overestimated. Aileron deflections obtained in the NACA flight tests of the ailerons exceeded the deflections shown by the curve by substantial amounts.

Condition II (design load for triangular distribution). - A second and more rational condition assumed in the design is a design load of 183 pounds per square foot (applied load $1/1.5 \times 183$ lb per sq ft) with triangular distribution. This curve was used to establish the limiting aileron deflections in the NACA tests.

Condition III (static test-breaking load). - The curve of condition III shows the aileron deflections and airspeeds at which the air loads presumably would equal the static test breaking load of 210 pounds per square foot.

A comparison of the data of figures 2 and 5 shows that at high speeds the limiting aileron deflections shown for condition II could be reached with a minimum applied stick force of about 56 pounds. With a stick force of 70 pounds,

70 pounds being a reasonable upper limit for the maximum pilot's effort, the limits of condition II would be slightly exceeded.

It appears, therefore, that the reduction in aileron operating forces obtained with the beveled trailing-edge balance should not be carried further without, at the same time, strengthening the structure and possibly the wing structure.

CONCLUDING REMARKS

From a consideration of the results shown in this report and the report of reference 1, it is evident that a considerable improvement in the lateral control characteristics of the XP-51 airplane was effected by the installation of the beveled trailing-edge ailerons with increased travel. The greatest improvement was evidenced at low and moderate speeds where the aileron effectiveness was increased 55 percent to 70 percent over that of the original ailerons. At high speeds the roll obtained for a given stick force was from 20 percent to 40 percent greater than that obtainable with the original XP-51 ailerons and appears to be as great as the strength of the present wing and aileron structure will permit.

In general, the lateral control characteristics with the modified ailerons may be said to be comparable with those of such airplanes as the P-40 and the XP-60 which, in that respect, are among the most satisfactory tested.

If further lightening of the aileron stick forces of the XP-51 is attempted, the strength of the wing-aileron structure should be reexamined in detail since the safe limits of deflections as regards the aileron strength are now attained with a stick force of only 56 pounds.

It appears advisable to avoid the use of a trimming tab on the ailerons having beveled trailing edges in view of the uncertain characteristics exhibited in the present tests. The small variations of trimming forces that occurred without the trimming tab could either be ignored or taken care of with a bungee.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 27, 1942.

REFERENCE

1. White, M. D., and Hoover, Herbert H.: Flight Tests of Modifications to Improve the Aileron Control Characteristics of a North American XP-51 Airplane. (A. C. No. 41-38). NACA MR, June 20, 1942.

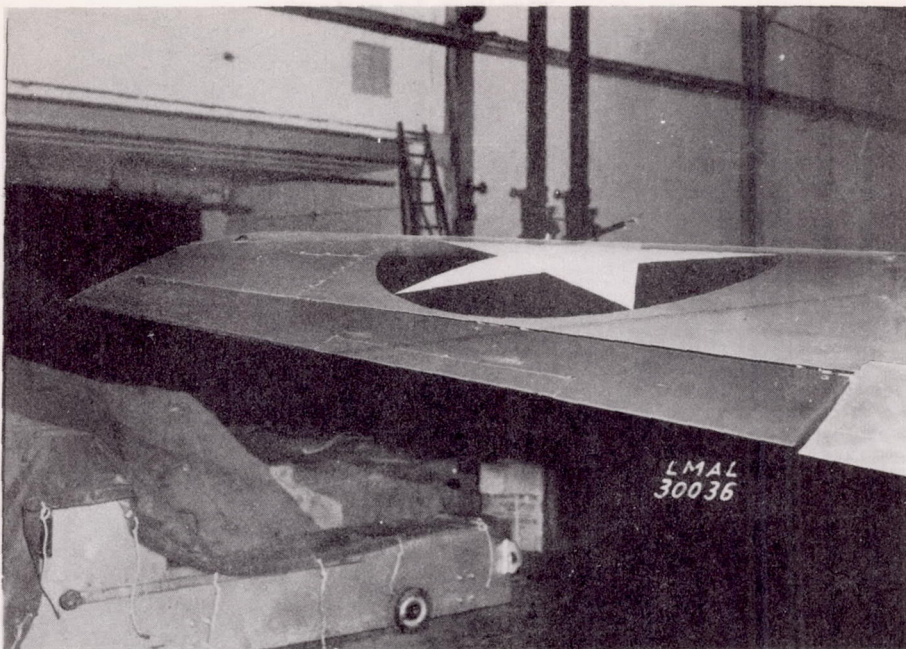


FIGURE 1(A). - VIEW OF REBUILT AILERON ON LEFT WING OF XP-51 AIRPLANE.

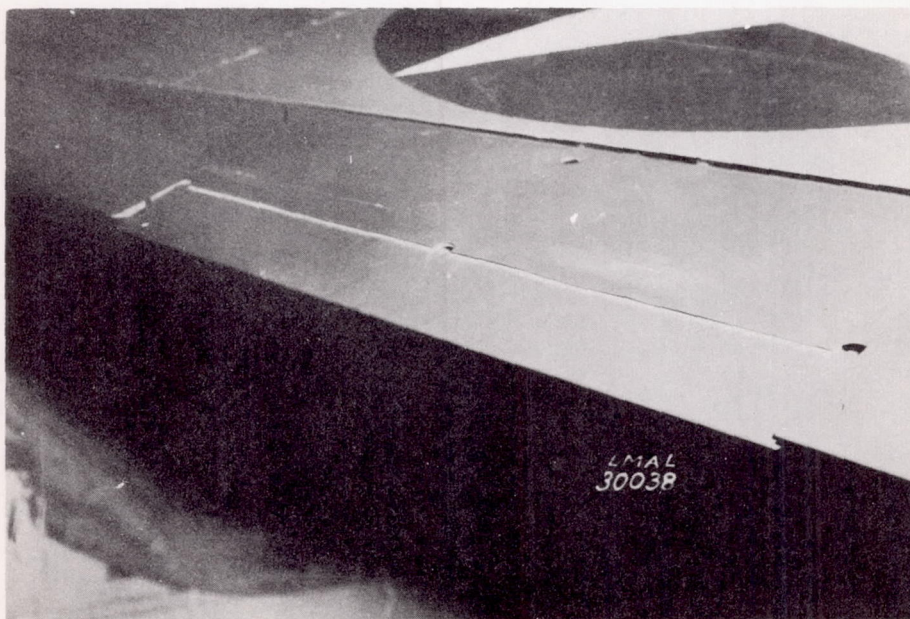


FIGURE 1(B). - CLOSE-UP VIEW OF TRIM TAB ON REBUILT AILERON ON LEFT WING OF XP-51 AIRPLANE. TAB DEFLECTED DOWN.

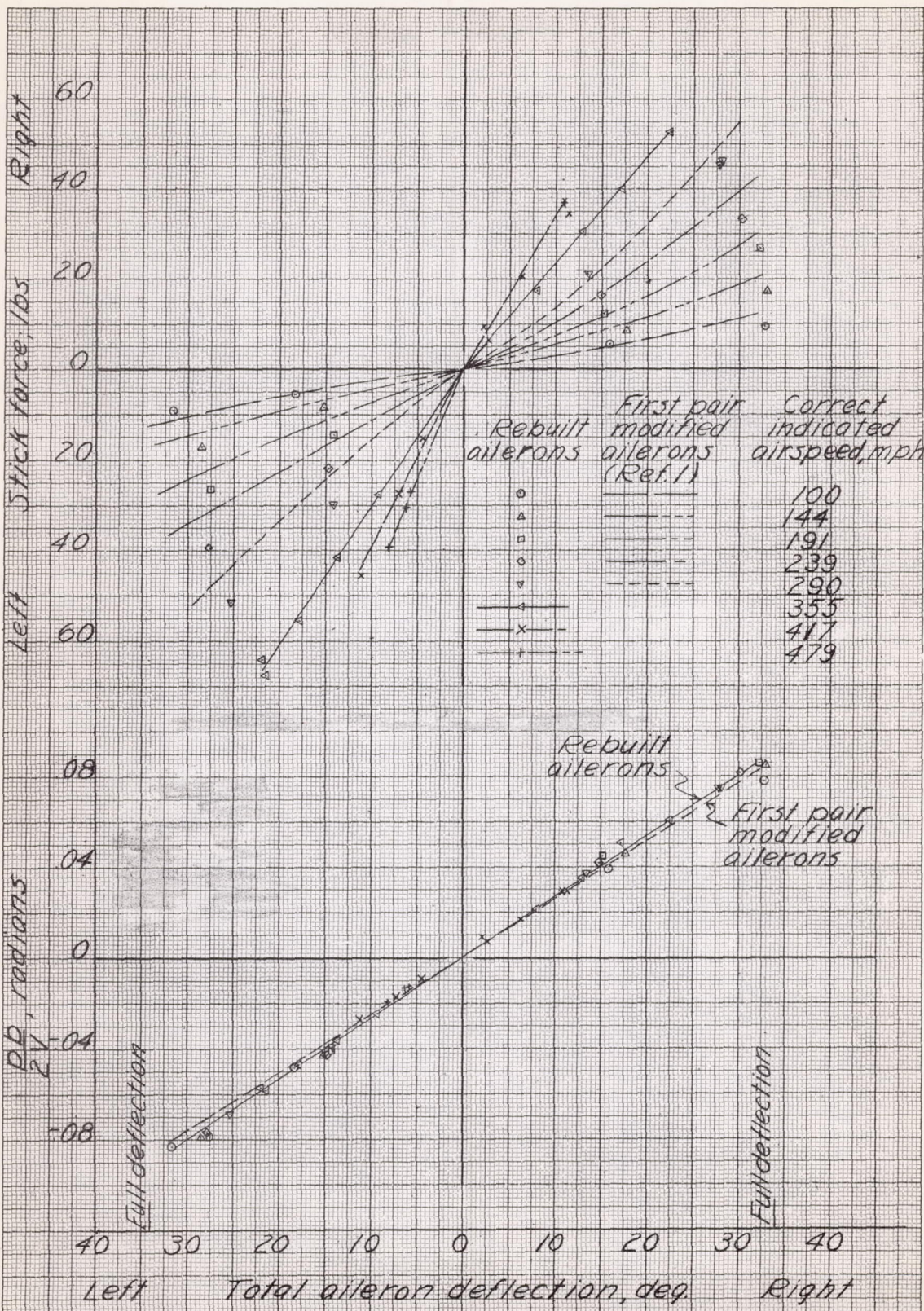
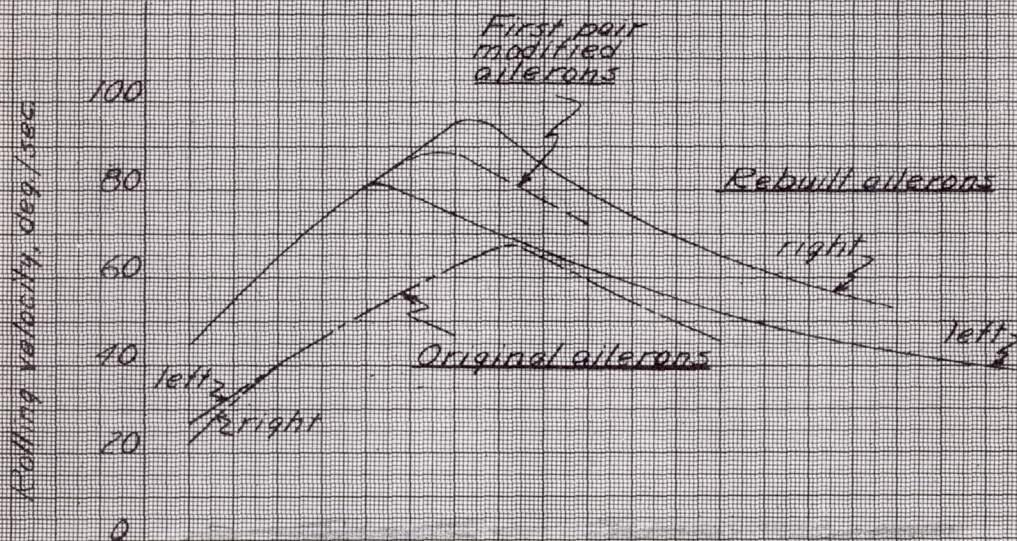


Figure 2- Aileron effectiveness and forces. Beveled trailing edge ailerons. North American XP-51 airplane

(a) Maximum rolling velocity at 10,000 ft. altitude



(b) Maximum pb

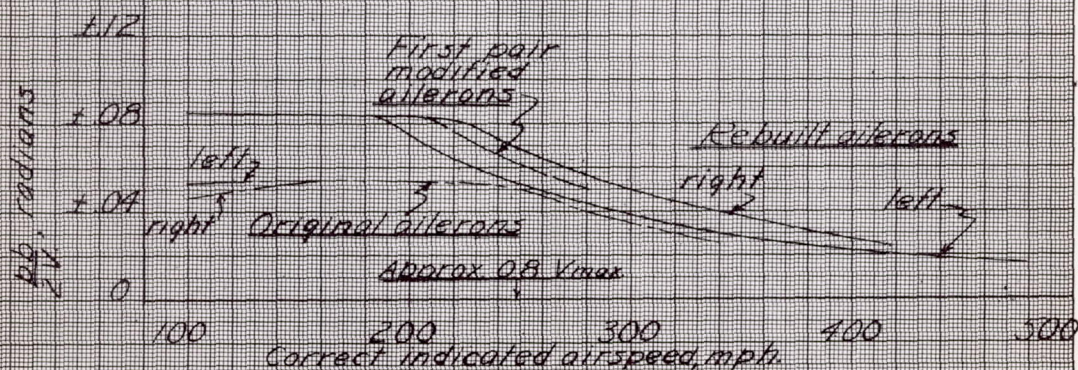


Figure 3- Aileron characteristics of North American XP-51 airplane (A.C. No. 41-38) with modified and original ailerons in aileron rolls with 30 pounds stick force.

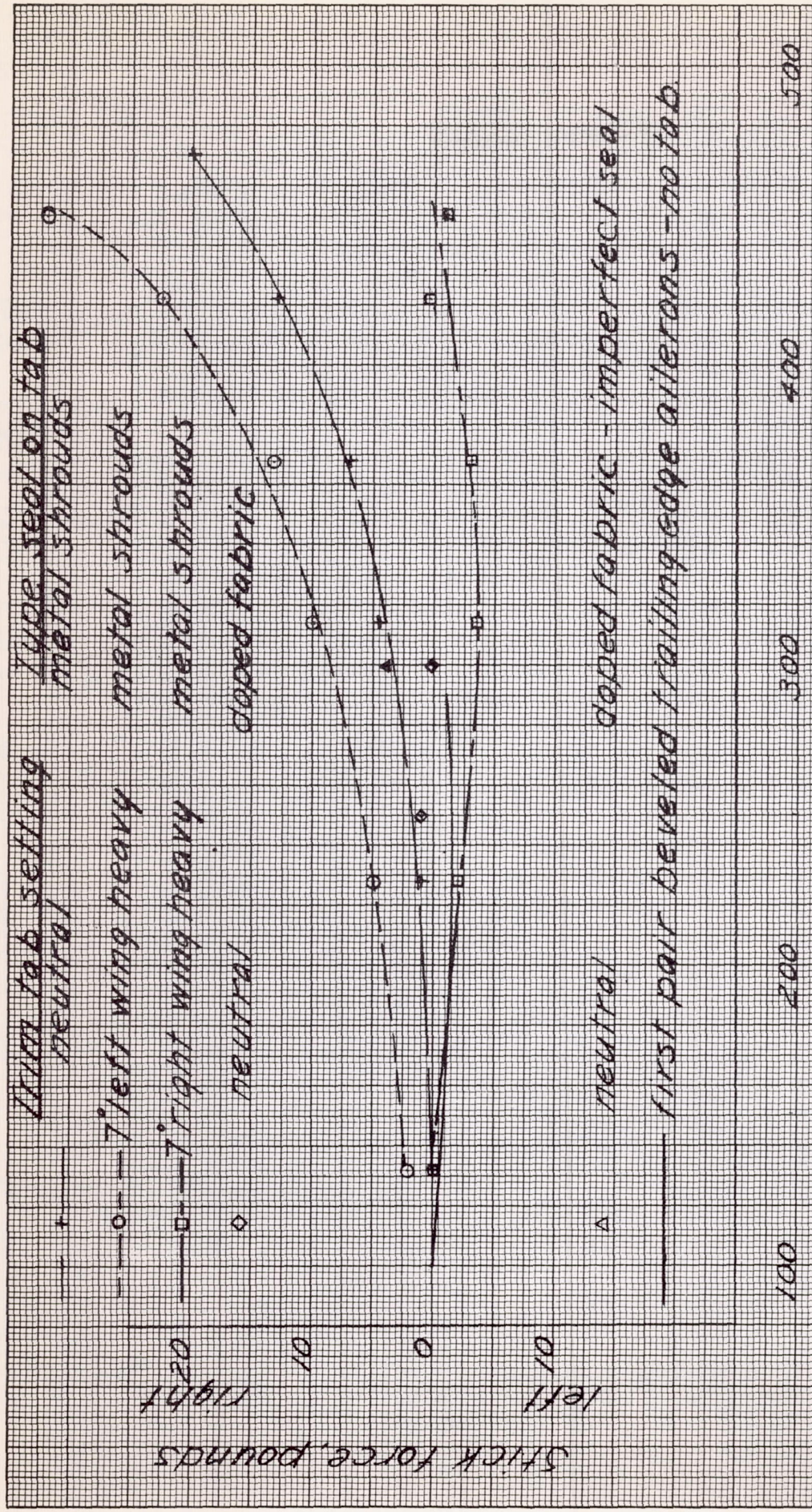


Figure 4.-Aileron trim forces with beveled trailing-edge ailerons, North American XP-51 airplane (A.C. No. 41-38).

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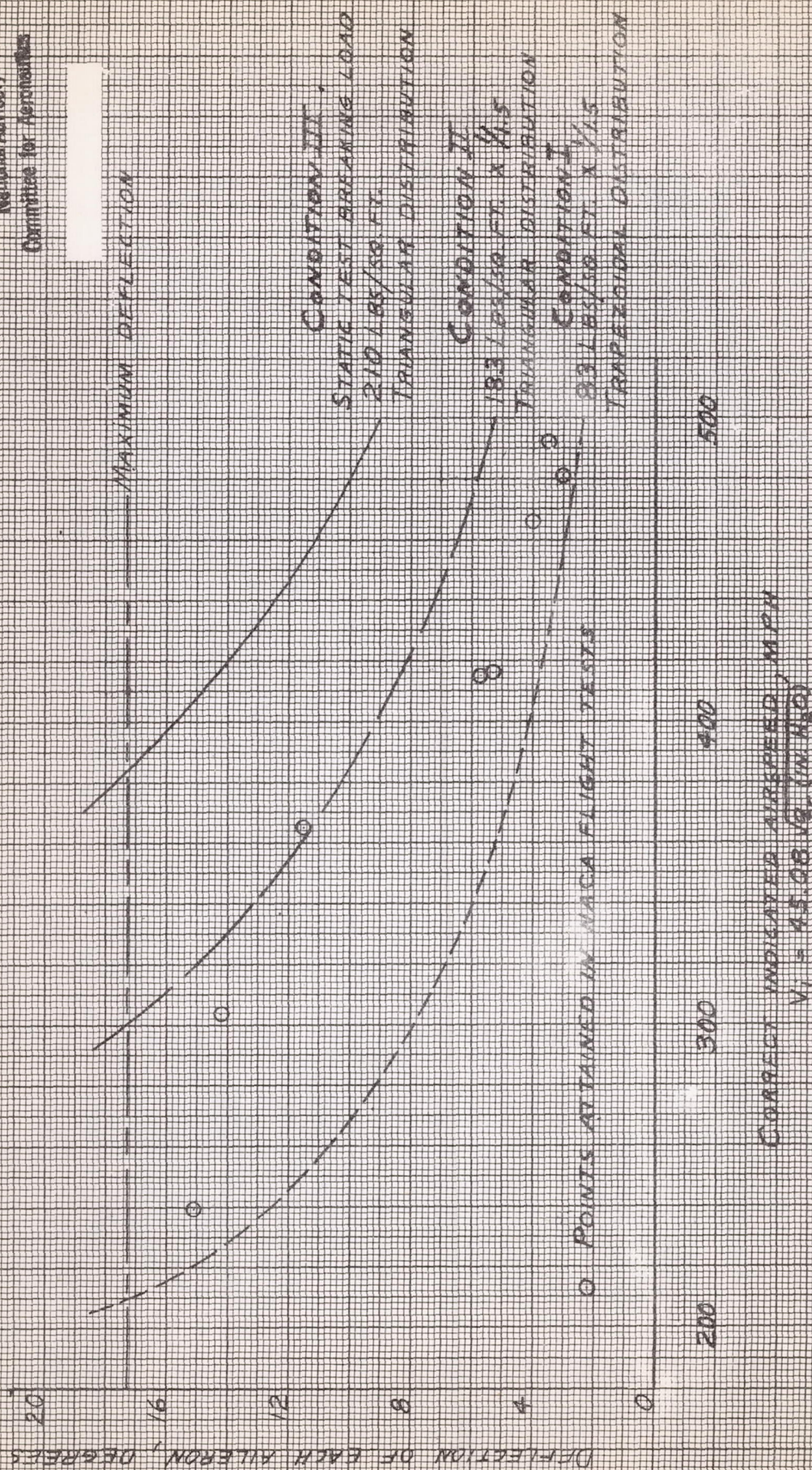


FIG. 5- RELATION BETWEEN AILERON STRENGTH AND APPLIED LOADS AT DIFFERENT AIRSPEEDS AND DEFLECTIONS. XP-51 AIRPLANE